EQA *– Environmental quality / Qualité de l'Environnement / Qualità ambientale,* **35 (2019) 33-50**

LEVELS OF HEAVY METALS AND CONTAMINATION STATUS OF A DECOMMISSIONED TAILINGS DAM IN GHANA

Emmanuel Sey (1)*, Ebenezer J.D. Belford (2)

(1) Department of Materials Engineering,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
(2) Department of Theoretical and Applied Biology,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

*Corresponding author E,mail: mongomii@yahoo.com

Abstract

Heavy metal pollution from tailings has become a major global concern due to its toxicity, persistence and accumulative potential with detrimental effects on public health and environmental receptors. In a bid to determine the contamination status of a decommissioned tailings storage facility (TSF 2) from the Chirano Gold Mine (CGM), nine core samples of mine tailings were collected down to a depth of 20 cm within a 8100 m^2 grid. Concentrations of As (0.7 to 3.3), Pb (1.3 to 2.2), Cr (0.9 to 1.9), Cd (2.0 to 2.6), Cu (5.5 to 6.5), Zn (2.4 to 3.6) and Fe (4.5 to 12) mg/kg were below FAO/WHO permissible limits. Concentration of heavy metals statistically varied between sampling sites ($p < 0.05$). The geoaccumulation index and contamination factor revealed that, TSF 2 is uncontaminated with As, Pb, Cr, Cu, Zn and Fe. However, mine tailings were significantly enriched with Cd, and thus likely to pose ecological risk to the surrounding environment. In general, the tailings dam is not progressively deteriorating in accordance to pollution load index. Findings of this study would contribute to the environmental database of gold mine tailing at CGM to assist future remediation of the tailing storage facility.

Introduction

Mining forms an important component of global economy growth. Mining of precious metals is one of the important sources of foreign exchange in most developing countries. In Ghana, total earnings from mineral export in 2015 amounted to US$ 3,322.61 million (GIPC, 2017). In terms of direct domestic revenue, the mining sector contributed US$ 269,821,500 (GBN, 2017). However, the extraction and processing of the precious metal usually comes with a great cost to the environment and on public health. For example, mine tailings generated from ore processing serves as a source of contamination to the environment (Roussel et al., 2000). The predominant contaminants mostly found in these tailings are heavy metals and residual reagents such as cyanide. The heavy metals are naturally occurring element with density greater than of 6 g/cm^3 (Thornton *et al.*, 1995). As a result of physical and chemical property changes associated with the lithosphere,

DOI: 10.6092/issn.2281-4485/9060

this contaminant in mine tailings can be carried, spread to and accumulated in animals and plants, up into the food chain to man as the ultimate consumer (Kim et al., 2000). Also, heavy metals primarily liberated by mining operations ends up in the component of the earth surface layers persisting for years (Gosar, 2004). Thus, due to their soluble and mobile nature, they may be released into surface and ground water systems as well as other geological environment (Jang et al., 2005). Again, heavy metals in mine tailing have tendency to cause terminal disease when accumulated in human internal organs through water and crops in take (Lee et al., 2007). The presence of high levels of Cu in the human body may cause vomiting and damage the liver (Vick, 1990). Cd and As are said to be highly poisonous and carcinogenic with ability to accumulate in the kidney and liver. According to the WHO, Pb exposes adults to increase risk of high blood pressure, anaemia, damage to kidney and birth problems such as miscarriage. However, according to Bempah *et al.* (2013) heavy metals research such as Arsenic (As) in Ghana mostly focus on environmental receptors, consumables (vegetables and fruits) with dearth research of heavy metals in gold mine tailing. Also, with an engineered Tailing Storage Facility (TSF), in the assessment of heavy metals, much emphasizes is placed on the water (decant pond) on the surface of the TSF whilst limited analysis of heavy metals is periodically conducted for the soil tailings (consolidated tailings). For these soil tailings dams to be put into productive use, the levels of heavy metals must be assessed. Therefore, this study seeks to investigate the presence of As, Pb, Cr, Cd, Cu, Zn and Fe and the contamination status of a decommissioned tailings dam from the CGM in Ghana.

Keywords: *Contamination factor, Geoaccumulation index, Enrichment factor, Pollution Load index, Ecological Risk factor*

Materials and Methods

Study site

Chirano Gold Mines Limited (CGML) is a major mining company located in the Western North Region of Ghana specifically between Bibiani-Anhwiaso-Bekwai and Sefwi-Wiawso Districts (Figure 1). It is situated at Latitude 6°00’00’’ N and 6°24’75’’ N and Longitude 2°21’33’’ W and 2°24’33’’ W and about 100 km south-west of the city of Kumasi, 15 km south-southwest of the township of Bibiani. The concessional area is 45 km^2. Gold deposits lie close to a splay off the main Bibiani shear zone known as the Chirano Shear. The capacity of the firm’s mill is about 3.5 million ton/annum (Mtpa). The annual rainfall ranges from 1056.2 to 1929.0 mm with a mean rainfall of 1472.7 mm but varies annually.

Sampling design

Tailings samples were collected from a decommissioned Tailings Storage Facility (TSF 2) (Figure 2). Samples were collected from a 90 m x 90 m square grid using systematic composite sampling technique. Three separate sub-plots P1, P2, P3 (90 m x 30 m each) were demarcated within the main plot.

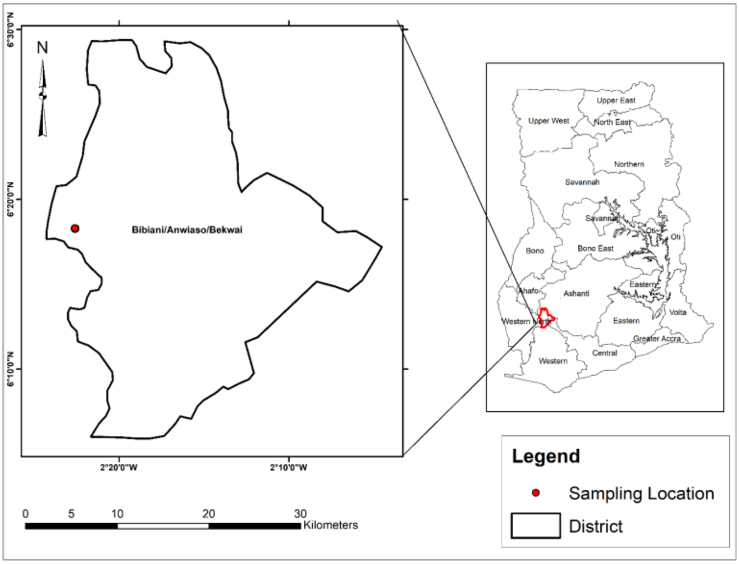

Figure 1
Study site

Nine 30 m x 30 m sampling sites (P1S1, P1S2, P1S3, P2S1, P2S2, P2S3, P3S1, P3S2 and P3S3) were demarcated along the sub-plots.

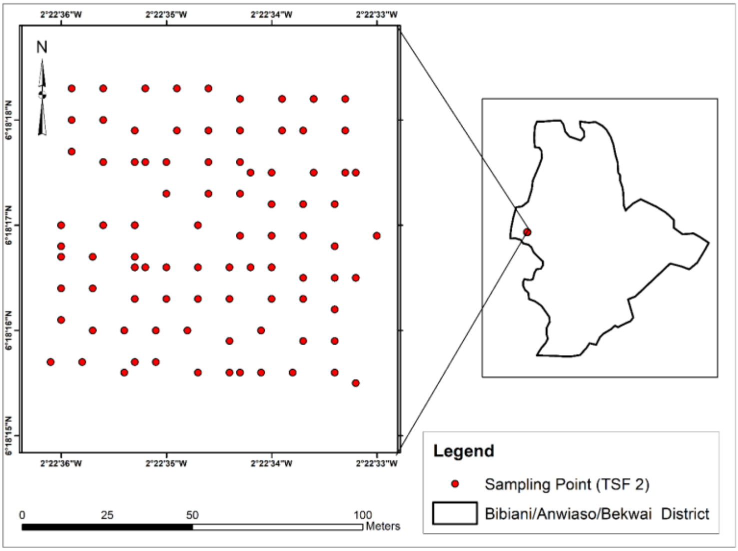

Figure 2
Sampling location with sampling points

At each demarcated sampling site, scoop of soil samples were collected down to a depth of 20 cm with hand trowel from nine different sampling points at 10 m apart. Sets of three samples along a column, from the nine sampling points, within each sampling sites were composited and placed into a well labelled ziploc bag. Each sampling site had three replicates of composited soil samples. Thus, each sampling

DOI: 10.6092/issn.2281-4485/9060

site was composed of 9 sampling points, giving a total of 81 sampling points and 27 replicate samples. All sampling points were recorded using hand-held GPS on site. Soil samples were transported to Materials and Civil Engineering Laboratory, Kwame Nkrumah University Science and Technology (KNUST) for further treatment and analysis.

Sample preparation and analytical methods

Determination of pH, EC and particle sizes of tailings samples. Samples were air dried for 7 days in the laboratory, passed through a 0.2 mm sieve, homogenized and stored in ziploc bags for subsequent analysis. Soil pH and EC were determined using glass electrode (PC 300 series - Cyberscan) in a soil-water ratio 1:2.5 (Rhoades, 1982). Particle size analysis was carried out using the standard procedures outlined in BS 1377 (1990). The mass percentage of particles sizes or cumulative percentages by mass of the sample passing each of the sieves was plotted on a semi-logarithmic scale using the general relationship, equation [1];

% passing this sieve = (% passing previous sieve)-(% retained on this sieve [1]

Determination of Mineralogical Composition. About 10 g of dried samples in a well labelled sterile ziploc bags were taken for XRD analysis at the Department of Physics, University of Ghana. Samples were further grounded into powered form with the aid of a pestle in a ceramic bowl and homogenized. The homogenized powdered samples were placed into the XRD machine (PAN analytical Empyrean Series 2 X-Ray Diffraction XRD). The XRD analysis was then carried out with Cu K-alpha radiations, 45 kV and 40 mA 2θ range scanned from 5-89°, step 0.0400 and counting time of 60 sec. Identification of mineral phase was done with Jade software package coupled with diffraction data bases.

Determination of heavy metals. Soil sample (1 g) was weighed into 250 ml digestion flask. The sample was dissolved using Tri-Acid Mixture [H_2SO_4: HNO_3: $HClO_4$ = 5:1:1 (10 ml)] (Twyman, 2005). Digestion was subsequently carried out on a hot plate for 10 minutes under fumes chamber until dense fumes evolved. Digested samples were cooled and the solution was filtered through a Whatman 1 filter paper into 50 ml volumetric flask. The volume was made to the 50 ml mark by adding distilled water. To ensure quality assurance of digested samples, blank was prepared to check for background contamination introduced by reagents used. The blank sample contained {H_2SO_4: HNO_3: $HClO_4$ = 5:1:1 (10 ml)} which was heated for 10 minutes under fumes chamber, and volume made to the 50 ml mark by adding distilled water.

Instrumental calibration was prepared according to Knödel et al. (2007). As, Cd, Pb, Cr, Zn, Fe, and Cu concentrations were determined using Atomic Absorption Spectrometer (SPECTRA AA 220 Air-acetylene Flame).

Contamination Assessment Methods

Geoaccumulation Index. Geoaccumulation index (Igeo) for tailing samples were computed using the Igeo formula [2] introduced by Müller (1969):

$$\text{Igeo} = \log_2 (C_n/1.5B_n) \quad [2]$$

Where C_n is the measured concentration of the element in the samples. B_n is the geochemical background or pristine value of the element directly measured in pre-civilization or taken from literature (Ephraim and Ajayi, 2014; Mohiuddin et al., 2010). The factor 1.5 is introduced to minimize the effect of possible variations in the background values which may be attributed to lithologic variations in the sediments (Stoffers et al., 1986).

Igeo values were compared to the seven contamination categories or enrichment classes as classified by Müller (1969):

Class 0 : ($\text{Igeo} \leq 0$); uncontaminated
Class 1: ($0 < \text{Igeo} \leq 1$); uncontaminated to moderately contaminated
Class 2: ($1 < \text{Igeo} \leq 2$); moderately contaminated
Class 3: ($2 < \text{Igeo} \leq 3$); moderately to heavily contaminated
Class 4: ($3 < \text{Igeo} \leq 4$); strongly contaminated
Class 5 : ($4 < \text{Igeo} \leq 5$); strongly to extremely contaminated
Class 6 : ($\text{Igeo} > 5$); extremely contaminated

Enrichment Factor. Enrichment factor establish how much soil is unnaturally affected by a metal above background levels mainly through anthropogenic activities (Ho *et al.,* 2010). Accordingly, the anthropogenic impact on tailing samples were computed using EF as proposed by Solomons and Förstner (1984):

$$\text{Enrichment factor (EF)} = M_x \times Fe_b / M_b \times Fe_x \quad [3]$$

where, M_x and Fe_x are respective concentrations of the heavy metal and Fe in the sample material; M_b and Fe_b are their respective concentrations in a suitable baseline reference material. The reference metal used to normalize the measured heavy metal concentration was Fe. EF values of the samples were separated into different contamination categories as classified by Yongming et al. (2006):

Enrichment factor	Description
EF < 1	Background concentration
EF = 2-5	Moderate enrichment
EF = 5-20	Significant enrichment
EF = 20-40	Very high enrichment
EF > 40	Extremely high enrichment

Contamination Factor. Contamination factor necessitates that samples in minimum of five are combined to generate a mean pollutant concentration which is then matched to the background concentration (Abraham and Packer, 2008), according to the equation [4] introduced by Hakanson (1980):

$$\text{Contamination factor } (C_f) = M_x / M_b \quad [4]$$

where Mx is the mean concentration of heavy metal in sediment sample. M_b is the pre-industrial baseline/background reference value for the metal.

Hakanson (1980) separated C_f into: $C_f < 1$ signifies low contamination; $1 \leq C_f < 3$ signifies moderate contamination; $3 \leq C_f$ signifies considerable contamination; $C_f > 6$ signifies very high contamination status of a metal.

Pollution Load Index. The pollution load index (PLI) as proposed by Tomlinson et al. (1980) was used in this study. The PLI for a single site is the nth root of n number multiplying the contamination factors together:

$$\mathrm{PLI} = \sqrt[n]{\mathrm{CF1} \times \mathrm{CF2} \times \ldots\ldots \mathrm{CFn}} \qquad [5]$$

where CF = Contamination factor, n = number of metals to the nth root
According to Tomlinson *et al.* (1980) computed PLI value of 0.0 indicates perfection, a value of 1.0 indicate only baseline levels of pollutants present and values > 1.0 indicate progressive deterioration of the site quality. Numerical indices values were computed using background levels of metals in the upper continental crust: Pb (20 mg/kg), Cu (25 mg/kg), Zn (71 mg/kg), As (1.5 mg/kg), Cd (0.098 mg/kg), Cr (35 mg/kg) and Fe (4.49 mg/kg) described by Taylor and McLeenan (1985).

Ecological Risk Factor. The Ecological risk factor (Er) proposed by Tomlinson et al. (1980) was used in this study. The ecological risk of each metal was calculated as follows, equation [6]:

$$\mathrm{Er} = \mathrm{Tr} \times C_f^i \qquad [6]$$

where: Tr = Toxic response factor of a given element, C_f^i = Contamination factor .
The following expressions is used to define the ecological risk index as categorized by Hakanson (1980), $Er<40$ indicate low potential ecological risk, $40<Er<80$ moderate potential ecological risk, $80 < Er < 160$ considerable potential ecological risk, $160<Er<320$ high potential ecological risk, ≥ 320 very high potential ecological risk.

Data analysis

Data obtained from the study was expressed as mean and standard deviation using Statistical Package for Social Sciences (SPSS) version 20. Subsequently, one-way analysis of variance (ANOVA) was use to rank and compare means at 5% level of significance. Geoaccumulation Index (Igeo), enrichment Factor (EF) contamination degree (Cd), modified degree of contamination (mCd), pollution Load Index (PLI), ecological risk factor (Er) were calculated using Microsoft Excel 2013.

Results and Discussion

Physicochemical properties of tailing samplings in TSF 2

The tailing samples were slightly alkaline with pH value ranging from 8.5 to 8.8 (Table 1). Similar range of pH value (7.1-9.4) of tailings was reported by Singo (2013) in Musina, South Africa. Previous study conducted by Remy (2013) revealed that, soils at Chirano are neutral in nature. The alkaline nature of the tailing samples could be attributed to the basic chemical (lime) used during the beneficiation process to immobilize metal at CGM. The alkaline nature of the samples also suggest that, tailings in CGM is not acid generating (less occurrence of sulphide minerals) as compared to tailings around Incheon Au-Ag mine in Korea, having a pH of 1.9 - 7.4 (Jung, 2001; Enkhzaya et al., 2016). Bempah et al. (2013) observed that, the mobility of As in tailings mud was greatly affected in slightly alkaline condition. Also, most mobile heavy metals such as Cd and Zn in neutral and alkaline soils become immobile in comparism to highly acidic soil medium (Sherene, 2010; Fijalkowski et al., 2012; Nkansah, 2016). Consequently, the alkaline nature of tailings could have restricted the mobility of such metals in TSF2. The electrical conductivity ranged from 280 to 2570 µs/cm reflecting high salinity levels in TSF2. The high salinity levels of mine tailing samples is basically attributed to the presence of soluble salts (calcium, sodium, magnesium, carbonate) in the tailings as indicated by the XRD results (Fig. 1). In terms of metal behaviour, the high pH and high salinity could facilitate the mobility of Cd (Micó et al., 2006; Peris et al., 2007; Tian et al., 2017). There were statistically differences ($p < 0.05$) in the levels of pH and EC between plots at TSF 2. The differences may possibly be due to the fact that, ore from which the tailings were produced were not necessarily sourced from the same pit and each pit has its own geochemical features (Jeleni *et al.*, 2012).

Table 1
Physicochemical properties of tailing

Site	pH	EC (µs/ cm)
PIS1	8.5^{a}	358^{b}
P1S2	8.6^{bc}	534^{d}
PIS3	8.7^{bcd}	435.3^{c}
P2S1	8.7^{cde}	913^{f}
P2S2	8.8^{e}	1507^{g}
P2S3	8.6^{cde}	2570^{h}
P3S1	8.6^{ab}	280^{a}
P3S2	8.5^{a}	620^{e}
P3S3	8.8^{de}	1524^{g}

Mean in the same column with different superscript differs significantly ($p < 0.05$)

Mineralogical composition of tailings

The XRD analysis revealed 3 dominant phases of minerals namely the oxide group, silicate group and the carbonate group. In Plot 1, 2 and 3 the mineral phases were Quartz (SiO_2), Dolomite $CaMg(CO_3)_2$ and Albite ($NaAlSi_3O_8$) (Figure 3).

Quartz (SiO_2) recorded the highest compound phase with a value of 61, 56, and 64 for Plot 1, Plot 2 and Plot 3 respectively. Similar findings about the dominance of quartz than other minerals in tailings were also reported in studies conducted by Novhe et al. (2014) and Munyai et al. (2016).

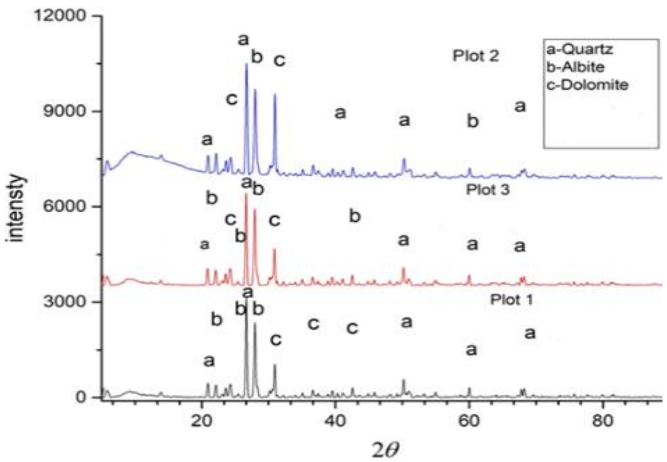

Figure 3
Mineralogical composition

The low concentration or percentage of acid forming sulphidic minerals in all mine tailings samples indicates that, the generation of Acid Mine Drainage (AMD) is unlikely in TSF 2. Therefore, there is a very low possibility of contamination of surrounding water bodies as a result of AMD. Eriksson (2002) stated that with time, the presence of Acid Neutralizing Minerals (Dolomite) in mining waste (tailings) maintains a neutral pH and enhance the precipitation of dissolve metals..

Particle size distribution and texture of the tailings

The texture of the tailing samples in TSF 2 for Plot1, Plot2 and Plot3 were silty sand with particle size ranging from 0.0015 to 2.0 mm (Fig. 4).

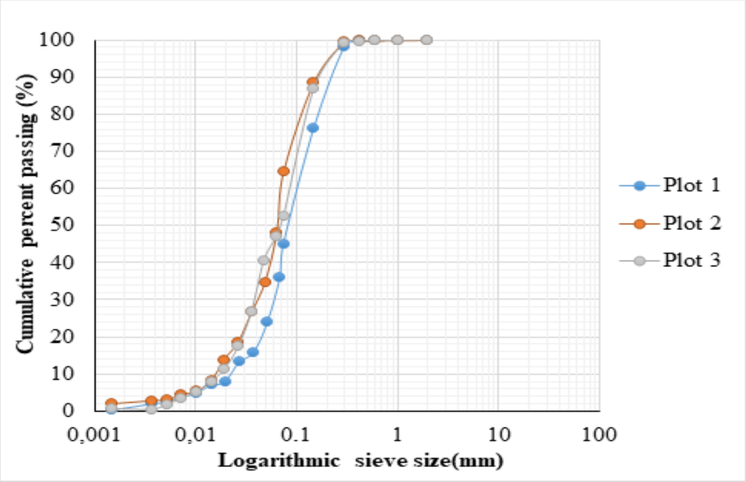

Figure 4
Particle size distribution curves for tailing samples

Similar particle size of tailing was reported by Foli (2017), in a decommissioned tailings dam at AngloGold-Ashanti, Obuasi Mine. Plot1 contained 36% silt and 64% sand fractions, Plot2 contained 48% silt and 52% sand fractions, and Plot3 contained 47% silt and 53% sand fractions. Indication is that, Plot 1 had lesser proportion of the small particle sizes compared to Plot2 and Plot3 respectively.

Also, the deficiency of clay materials in the tailing could be a risk to ground water resources, as according to Boateng et al. (2012) the surface of clay materials greatly adsorb trace metals under appropriate geochemical condition and with high levels of Fe in the medium. Thus, the texture of tailings may enhance the permeability of toxic substances to ground water resources.

Concentration of heavy metals for various sampling sites

Due to the toxicity of Arsenic (As), it is considered as one of the most dangerous metals with serious environmental concerns (Choudhury et al., 2011). Exposure to As causes cancer of the lungs, urinary bladder and kidney damage (Abdul-Wahab and Marikar, 2012). Concentration of As for all sampling sites ranged from 0.7 mg/kg in P1S1 to 3.3 mg/kg in P2S3 and were below FAO/WHO (2001), maximum permissible limit of 20 mg/kg (Table 2). Contrary to this finding, higher concentration (1752 mg/kg) in gold mine tailings was observed by Bempah et al. (2013) in AngloGold-Ashanti, Obuasi Mine. In gold ore bodies, As occurs in sulphide minerals such arsenopyrite (FeAsS) Nriagu et al. (2007), hence, the low levels of As in TSF 2 could be attributed to the absence or low concentration of arsenopyrite (FeAsS) in the tailings samples. There were significant difference ($p < 0.05$) in the concentration of As between the means of P2S3 and P3S3 with all other treatment means.

Lead (Pb) is another metal of great concern because it is a metal that can cause genetic mutation. The concentration of Pb for all sampling sites ranged from 1.3 mg/kg in P2S2 to 2.2 mg/kg in P2S1 and were below FAO/WHO (2001), maximum permissible limit of 50 mg/kg (Table 2). Generally, there were significant difference ($p < 0.05$) in the concentration of Pb between sampling sites. According to Matocha et al. (2001) in gold ore, Pb occurs in the form of galena (PbS) with elevated levels determined by high concentration of sulphide, hence the low levels of Pb in all sampling sites could be attributed to the absence of PbS in the tailings.

Chromium (Cr) concentration for all sampling sites were below FAO/WHO (2001), maximum permissible limit of 100 mg/kg ranging from 0.9 mg/kg in P3S3 to 1.9 mg/kg in P2S1 (Table 2). Generally, there were significant difference ($p < 0.05$) in the concentration of Cr between sampling sites.

Due to the high stability and toxicity of cadmium (Cd), it is considered as the most dangerous metal ion (Kermani et al., 2010). The concentration of Cd for all sampling sites were below FAO/WHO (2001), maximum permissible limit of 3 mg/kg ranging from 2.0 mg/kg in P1S3 to 2.9 mg/kg in P1S1 (Table 2). Generally, there were significant difference in the concentration of Cd between sampling sites.

Copper (Cu) concentration for all sampling sites ranged from 5.5 mg/kg in P1S3 to 6.5 mg/kg in P2S3, and were below FAO/WHO (2001), maximum permissible limit of 100 mg/kg (Table 2). Comparatively similar lower concentration (92.17 mg/kg) in tailings below the FAO/WHO (2001) maximum permissible limit was

DOI: 10.6092/issn.2281-4485/9060

observed by Bempah et al. (2013) in Obuasi. Generally, there were significant difference in the concentration of Cu between sampling sites.

Zinc (Zn) concentration for all sampling sites ranged from 2.4 mg/kg in P1S3 to 3.6 mg/kg in P3S1 and were below FAO/WHO (2001), maximum permissible limit of 300 mg/kg (Table 2). Generally, there were significant difference in the concentration of Zn between sampling sites. Comparatively similar much lower concentration (2.8 mg/kg) in tailings below the FAO/WHO (2001) maximum permissible limit was also observed by Belford and Nkansah (2017) in CGML. In ore bodies, zinc occurs in the form of sphalerite (ZnS) which is regularly allied with galena Fashola et al. (2016), hence, the low levels of Zn in all samplings sites could be attributed to the absence or low concentration of (ZnS) in the tailings samples.

The concentration of iron (Fe) was the highest for all sampling sites but were below FAO/WHO (2001), maximum permissible limit of 50,000 mg/kg ranging from 4.5 mg/kg in P1S3 to 12.0 mg/kg in P3S3 (Table 2). As such, the order of abundance of metals in TSF 2 was Fe > Cu > Zn > Cd > Pb > Cr > As. Generally, there is relatively high natural deposit of Fe in the earth crust (Abrahim and Parker 2008). This could explain the high levels of Fe in all analysed tailings samples. There was significant difference ($p < 0.05$) in the concentration of Fe between the mean of P1S3 with the means of P1S1, P1S2, P3S1, P3S2 and P3S3.

Table 2. *Mean concentration of heavy metals at various sampling sites*

Plot	Site	Mean Concentration of Heavy Metal in Tailings (mg/kg)						
		As	**Pb**	**Cr**	**Cd**	**Cu**	**Zn**	**Fe**
1	P1S1	0.7±0.1^{a}	1.6±0.1^{b}	1.4±0.1^{bc}	2.9±0.1^{f}	5.7±0.1^{ab}	2.6±0.1^{b}	10.9±0.1^{b}
	P1S2	0.9±0.1^{abc}	1.8±0.1^{bc}	1.5±0.1^{c}	2.1±0.1^{ab}	5.9±0.1^{bc}	2.9±0.1^{c}	11.2±0.1^{b}
	P1S3	1.2±0.1^{cd}	1.9±0.1^{cd}	1.8±0.1^{ef}	2.0±0.1^{a}	5.5±0.1^{a}	2.4±0.1^{a}	4.5±5.8^{a}
2	P2S1	1.1±0.1^{bc}	2.2±0.1^{e}	1.9±0.1^{f}	2.2±0.0^{bc}	6.3±0.1^{ef}	3.4±0.1^{ef}	8.5±0.1^{ab}
	P2S2	1.5±0.1^{d}	1.3±0.1^{a}	1.8±0.1^{ef}	2.4±0.1^{de}	6.2±0.1^{de}	2.9±0.1^{cd}	8.8±0.1^{ab}
	P2S3	3.3±0.1^{f}	1.4±0.1^{a}	1.7±0.1^{de}	2.6±0.1^{e}	6.5±0.01^{f}	3.2±0.1^{de}	8.9±0.1^{ab}
3	P3S1	0.9±0.1^{ab}	2.2±0.1^{e}	1.6±0.1^{cd}	2.4±0.1^{de}	6.0±0.1^{cd}	3.6±0.1^{f}	11.7±0.1^{b}
	P3S2	0.9±0.1^{ab}	2.1±0.1^{de}	1.3±0.1^{b}	2.1±0.1^{ab}	5.8±0.1^{bc}	3.0±0.1^{cd}	11.7±0.1^{b}
	P3S3	2.4±0.1^{e}	1.8±0.1^{bc}	0.9±0.01^{a}	2.3±0.1^{cd}	6.1±0.1^{de}	3.1±0.1^{cd}	12.0±0.1^{b}
FAO/WHO guideline		**20**	**50**	**100**	**3**	**100**	**300**	**50000**

Means ±SD in the same column with different letters in superscripts differs significantly ($p < 0.05$)

In principal, the observed statistical differences in the distribution of heavy metals between sampling sites could be ascribed to variations in the physicochemical parameters (pH, EC, soil textural class) in the mine tailings samples. The variations also affirm the heterogeneous nature of tailings and significant non-uniform distribution of heavy metals in TSF 2 (Table 1). In terms of distribution of heavy metals according to plots, the order of abundance was Plot 2 > Plot 3 > Plot 1. The relatively high levels of metals in Plot 2 and Plot 3 comparative to Plot 1 may be due to lesser proportion of the small particle size in Plot 1. According to Munyai et al. (2016) smaller particles have a large surface area and thus likely to liberate metals in high concentrations. It is therefore likely that, metals will be easily leached from Plot 2 and Plot 3 compared to Plot 1.

Contamination Status of Heavy Metals

Geoaccumulation index. Negative Igeo values were recorded for Pb, Cr, Cu, Zn, and Fe for all sampling sites (Table 3). Clearly, there was practically uncontaminated state of Pb, Cr, Cu, Zn and Fe in the tailing samples. In the case of As, there was uncontaminated to moderate contamination with Igeo value of 0.5 at P2S3 and 0.1 at P3S3. Conversely, the Igeo index for Cd in all sampling site was in class 4 indicating strong Cd contamination. On the basis of the mean Igeo value mine, tailing in TSF 2 are enriched with heavy metals in a decreasing order: Cd > As > Cu > Pb > Cr > Zn > Fe.

Table 3 *Geoaccumulation Index values for tailing samples*

Site	As	Pb	Cr	Cd	Cu	Fe	Zn
P1S1	-1.7	-4.2	-5.3	**4.3**	-2.7	-12.2	-5.3
P1S2	-1.2	-4.1	-5.1	**3.8**	-2.7	-12.2	-5.2
PIS3	-0.9	-3.9	-4.9	**3.8**	-2.8	-13.5	-5.5
P2S1	-1.0	-3.8	-4.7	**3.9**	-2.6	-12.6	-4.9
P2S2	-0.6	-4.5	-4.9	**4.0**	-2.6	-12.6	-5.2
P2S3	**0.5**	-4.4	-4.9	**4.1**	-2.5	-12.5	-5.1
P3S1	-1.3	-3.8	-5.1	**4.0**	-2.6	-12.1	-4.9
P3S2	-1.3	-3.9	-5.4	**3.8**	-2.7	-12.1	-5.2
P3S3	**0.1**	-4.1	-5.7	**3.9**	-2.6	-12.1	-5.1
Mean	-0.8	-4.1	-5.1	**3.9**	-2.6	-12.4	-5.2

Note: Bold type means Igeo value within class 1-3

Enrichment Factor. The EF values for As, Pb , Cd, Cu, Zn and Fe were observed in the ranges of 0.2 to 1.1, 0.0 to 0.1, 0.0 to 0.1, 0.1 to 0.2, 0.0 to 0.0 and 1.0 to 1.0 indicating that, the principal source of these heavy metal were mainly from crust material signifying background metal concentration levels (Table 4).

Table 4 *Enrichment factor values for tailing samples*

Site	As	Pb	Cr	Cd	Cu	Fe	Zn
P1S1	0.2	0.0	0.0	**11.9**	0.1	1.0	0.0
P1S2	0.3	0.0	0.0	**8.5**	0.1	1.0	0.0
PIS3	0.8	0.1	0.1	**20.5**	0.2	1.0	0.0
P2S1	0.4	0.1	0.0	**11.9**	0.1	1.0	0.0
P2S2	0.5	0.0	0.0	**12.6**	0.1	1.0	0.0
P2S3	1.1	0.0	0.0	**13.1**	0.1	1.0	0.0
P3S1	0.2	0.0	0.0	**9.5**	0.1	1.0	0.0
P3S2	0.2	0.0	0.0	**8.2**	0.1	1.0	0.0
P3S3	0.6	0.03	0.0	**8.6**	0.1	1.0	0.0
Mean	0.5	0.02	0.1	**11.6**	0.1	1.0	0.0

Conversely, EF>2 were recorded for Cd in all tailing samples indicating significant enrichment of Cd in TSF 2. According to Enkhzaya et al. (2016) high EF value of heavy metal in tailing sample point to contribution of anthropogenic sources, indicating mine tailings enrichment by heavy metals during gold extraction process. Again, high concentration of heavy metals in a sample compared to continental crust can be major contamination source for soils and sediments (Levei et al., 2013). Hence, Cd which is carcinogenic could be transported into adjacent soils through moisture movement or wind erosion of dried tailings.

The order of heavy metal enrichment in the tailing samples are as follows: Cd>Fe>As>Cu>Cr>Pb>Zn.

Contamination Factor. Contamination factor (C_f) for sampling sites for As, Pb , Cr, Cd, Cu, Zn and Fe were observed in the ranges of 0.5 to 2.2, 0.1 to 0.1, 0.0 to 0.0, 20.4 to 29.1, 0.2 to 0.3, 0.0 to 0.1 and 0.00 to 0.00 respectively (Table 5). Accordingly, tailing samples can be classified as exhibiting low contamination status with respect to Pb, Cr, Cu, Zn and Fe for all sampling sites. However, As exhibited low contamination for all sampling sites with the exception of sampling site P2S3 and P3S3 which exhibited moderate contamination. The low contamination status of Pb, Cr, Cu, Zn and Fe in all sampling site may be attributed to the alkaline nature of tailing samples. With respect to Cd, a very high contamination status was observed in all mine tailing samples.

Table 5
Contamination factor heavy metals for tailing samples

Plot	**Site**	**Contamination Factor (C_f)**						
		As	**Pb**	**Cr**	**Cd**	**Cu**	**Zn**	**Fe**
1	PIS1	0.5	0.1	0.0	**29.1**	0.2	0.0	0.0
	P1S2	0.7	0.1	0.0	**21.2**	0.2	0.0	0.0
	P1S3	0.8	0.1	0.1	**20.4**	0.2	0.0	0.0
2	P2S1	0.7	0.1	0.1	**22.8**	0.3	0.0	0.0
	P2S2	0.9	0.1	0.1	**24.5**	0.3	0.0	0.0
	P2S3	**2.2**	0.1	0.1	**26.0**	0.3	0.1	0.0
3	P3S1	0.6	0.1	0.0	**24.7**	0.2	0.1	0.0
	P3S2	0.6	0.1	0.0	**21.4**	0.2	0.0	0.0
	P3S3	**1.7**	0.1	0.0	**23.2**	0.3	0.0	0.0
	Mean	**0.9**	**0.1**	**0.04**	**23.7**	**0.2**	**0.04**	**0.00**

Pollution Load Index Potential Ecological Risk Factor of Heavy Metals.Pollution index is a powerful tool for processing, analysing and conveying raw environmental information to decision makers, managers, technicians and the public (Caeiro et al., 2005). PLI values for the nine sampling sites PIS1, P1S2, P1S3, P2S1, P2S2, P2S3, P3S1, P3S2 and P3S3 ranged from 0.09 to 0.13 with the mean PLI of 0.11 (Table 6). Indication from dataset from the nine sampling site is that, even though tailing samples contain some level of heavy metals, the nine sampling site is not progressively deteriorating.

According to Angula (1996), the PLI is able to give an estimate of the metal contamination status and the necessary action that should be taken. Therefore, considering the relatively low metal concentration and the non-deteriorating nature of the sampling sites in TSF 2, drastic rectification measures may necessary not be required. However, the detection of all metals (Pb, As, Cd, Cr, Cu, Zn and Fe) in mine tailing samples still require that critical attention must be given to TSF 2.

Table 6 *PLI and potential ecological risk factor of heavy metals in mine tailings*

Site	PLI	As	Pb	Cr	Cd	Cu	Zn
PIS1	0.10	4.7	0.4	0.1	872	1.2	0.0
P1S2	0.11	6.5	0.5	0.1	637	1.2	0.0
P1S3	0.09	8.1	0.5	0.1	612	1.1	0.0
P2S1	0.12	7.3	0.6	0.1	683	1.3	0.1
P2S2	0.11	9.7	0.4	0.1	735	1.3	0.0
P2S3	0.13	21.7	0.4	0.1	781	1.3	0.1
P3S1	0.12	6.0	0.6	0.1	741	1.2	0.1
P3S2	0.11	6.1	0.5	0.1	643	1.2	0.1
P3S3	0.12	16.5	0.5	0.1	695	1.2	0.0
Mean	**0.11**	**9.6**	**0.5**	**0.1**	**711**	**1.2**	**0.04**

With respect to the toxicity of each heavy metals, the ecological risk factor (Er) for As was observed in the range of 4.7 to 16.5, that of Pb was in the range of 0.4 to 0.6, that of Cr was observed in the range of 0.1 to 0.1, that of Cu was observed in the range of 1.1 to 1.3, that of Zn was observed in the range of 0.0 to 0.1 (Table 6). Accordingly, As, Pb, Cr, Cu, Zn has low potential ecological risk factor in all sampling sites. Hence, these heavy metals were not likely to pose harm or ecological risk to the environment. However, higher Er value (612 to 872) were recorded for Cd in all sampling sites and likely to pose harm or ecological risk to the environment.

Conclusions

An investigation of heavy metals pollution in gold mine tailing soils were conducted in this study. All heavy metals under study were detected in all mine tailing samples. The mean concentration of As, Pb, Cr, Cd, Cu, Zn and Fe for all sampling sites were below FAO/WHO (2001) maximum permissible limits. Results also indicates that, there is a heterogeneous concentration of heavy metals in tailings as the levels varied between sampling sites. Tailing samples were silty sand hence, may lack the capacity to adsorb contaminants (trace metals) on its surface. The dominant mineral phase in the tailing sample was Quartz (SiO_2) hence, the production of AMD in TSF 2 is unlikely.

Based on geoaccumulation indices and contamination factor computed, TSF 2 can be generally described as uncontaminated with As, Pb, Cr, Cu, Zn and Fe. However, there was moderate contamination of As in sampling site P2S3 and P3S3. The enrichment factor revealed background concentration of As, Pb, Cr, Cu, Zn and Fe. In contrast, TSF 2 is highly contaminated with Cd. Also, mine tailings was significantly enriched with Cd and likely to pose ecological risk or harm to the environment. Hence, Cd should be a major priority in rehabilitation actions. In totality, the nine sampling site is not progressively deteriorating in accordance to

PLI values. Findings of this study may provide information and references for present and future management decisions regarding productive use of TSF 2.

References

ABRAHIM G. (2005). Holocene sediments of Tamaki Estuary: characterisation and impact of recent human activity on an urban estuary in Auckland, New Zealand (Doctoral dissertation, ResearchSpace Auckland).

ABRAHIM G.M.S, PARKER, R.J. (2008) Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environ. monitor. and assessment, 136(1-3):227-238. doi.org/10.1007/s10661-007-9678-2

ABDUL-WAHAB S. MARIKAR F. (2012) The environmental impact of gold mines: pollution by heavy metals. Open Eng., 2(2):304-313. doi.org/10.2478/s13531-011-0052-3

ANGULO E. (1996) The Tomlinson pollution load index applied to heavy metal,'Mussel-Watch'data: a useful index to assess coastal pollution. Sci. of the Ttl. Environ., 187(1):19-56. doi.org/10.1016/0048-9697(96)05128-5

BELFORD E. J, NKANSAH F. K. (2017) Heavy metals accumulation by indigenous plants growing in contaminated soil in a gold mining Area in Ghana. J. of Nat. Sci. Research, 7 (24):2224-3186

BEMPAH C.K., EWUSI A., OBIRI-YEBOAH S., ASABERE S.B., MENSAH F., BOATENG J. VOIGT H. J. (2013) Distribution of arsenic and heavy metals from mine tailings dams at Obuasi Municipality of Ghana. American J. of Eng. Research, 2(5):61-70.

BOATENG E., DOWUONA G.N.N., NUDE P.M., FOLI G., GYEKYE P., JAFARU H.M. (2012) Geochemical assessment of the impact of mine tailings reclamation on the quality of soils at AngloGold concession, Obuasi, Ghana. Research J. of Environ. and Earth Sci., 4(4):466-474.

BRITISH STANDARD 1377 (1990) British Standard Institution: Methods of test for soils for civil engineering purposes; Part 2, Classification tests 62p.

CAEIRO S., COSTA M.H., RAMOS T.B., FERNANDES F., SILVEIRA, N., COIMBRA, A., MEDEIROS, G., PAINHO, M. (2005) Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. Ecol. Indica., 5(2):151-169. doi.org/10.1016/j.ecolind.2005.02.001

CHOUDHURY B., CHOWDHURY S., BISWAS A.K. (2011) Regulation of growth and metabolism in rice (Oryza sativa L.) by arsenic and its possible reversal by phosphate. J. of Plnt Inter., 6(1):15-24. doi.org/10.1080/17429140903487552

ENKHZAYA S., OHE K., SHIOMORI K., OYUNTSETSEG B., BAYANJARGAL O., WATANABE M. (2016) Assessment of heavy metals in mining tailing around Boroo and Zuunkharaa gold mining areas of Mongolia. J. of Environ. Sci. and Tech., 9(5):379. Doi: 10.3923/jest.2016.379.389

EPHRAIM B. E., AJAYI I. O. (2014) Geoenvironmental assessments of heavy metals in surface sediments from some creeks of the Great Kwa River, Southeastern Nigeria. Journal of Environment and Earth Science, 4(21):15-26.

ERIKSSON N. (2002) Closure of mining waste facilities, Euromines.

FIJAŁKOWSKI K., KACPRZAK M., GROBELAK A., PLACEK A. (2012) The influence of selected soil parameters on the mobility of heavy metals in soils. Inżynieria i Ochrona środowiska, 15:81-92.

FOLI G. (2017) Arsenic remediation in mine drainage at the AngloGold-Ashanti Obuasi Mine in Ghana. A Ph. D (Doctoral dissertation, Thesis presented to Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

FAO/WHO- FOOD AND AGRICULTURAL ORGANIZATION/WORLD HEALTH ORGANIZATION (2001) Codex alimentarius commission. Food additives and contaminants. Joint FAO/WHO Food Standards Programme.

GBN- GHANA BUSINESS NEWS (2017) Mining sector contributes GH¢1.6 billion to Ghana's revenue in 2016, www.ghanabusinessnews.com (Accessed 4th October 2017).

GIPC- GHANA INVESTMENT PROMOTION CENTER (2017) Investing in Ghana's Mineral Processing Sector. www.gipcghana.com (Accessed 4th October 2017).

GOSAR M. (2004) Environmental impacts of metal minin. RMZ-Mat. and geoenviron., 51(4):2097-2107.

HAKANSON L. (1980) An ecological risk index for aquatic pollution control. A sedimentological approach. Water research, 14(8):975-1001. doi.org/10.1016/0043-1354(80)90143-8

HAN Y. M., DU P.X., CAO J. J., POSMENTIER E. S. (2006) Multivariate analysis of heavy metal contamination in urban dusts of Xi'an Central China. Sci. Total Environ. 355: 176-186. dx.doi.org/10.1016/j.scitotenv.2005.02.026

HO H.H., SWENNEN R., VAN DAMME A. (2010) Distribution and contamination status of heavy metals in estuarine sediments near Cua Ong Harbor, Ha Long Bay, Vietnam. Geologica belgica.

JANG M., HWANG J.S., CHOI S.I., PARK J.K. (2005) Remediation of arsenic-contaminated soils and washing effluents. Chemosphere, 60(3):pp.344-354. doi.org/10. 1016/ j.chemosphere.2004.12.018

JELENI M.N., GUMBO J.R., MUZERENGI C., DACOSTA F.A. (2012) An assessment of toxic metals in soda mine tailings and a native grass: a case study of an abandoned Nyala Magnesite mine, Limpopo, South Africa. WIT Trans. Ecol. Environ, 164:415-426.

KERMANI A., GHASEMI M.F., KHOSRAVAN A., FARAHMAND A., SHAKIBAIE M.R. (2010) Cadmium Bioremediation By Metal-Resistant Mutated Bacteria Isolated From Active Sludge Ofindustrial Effluent. Iranian J. of Environ. Health, Sci. and Eng., 7(3):229-286.

KNÖDEL K., LANGE G.,VOIGT H-J. (2007): Environmental Geology, Handbook of field methods and case studies. Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover Federal Institute for Geosciences and Natural Resources. Springer Berlin Heidelberg New York. pp 759–768.

LEVEI E., FRENTIU T., PONTA M., TANASELIA C., BORODI G. (2013) Characterization and assessment of potential environmental risk of tailings stored in seven impoundments in the Aries river basin, Western Romania. Chem. Cen. J., 7(1):5. doi.org/10.1186/1752-153X-7-5

LEE M., PAIK I.S., KIM I., KANG H., LEE S. (2007) Remediation of heavy metal contaminated groundwater originated from abandoned mine using lime and calcium carbonate. J. of hazard. mat., 144(1-2):208-214. doi.org/10.1016/j.jhazmat.2006.10.007

LOSKA K., WIECHUŁA D., KORUS,I. (2004) Metal contamination of farming soils affected by industry. Environ. Interna, 30(2):159-165. doi.org/10.1016/S0160-4120(03) 00157-0

MICÓ C., RECATALÁ L., PERIS M., SÁNCHEZ J. (2006) Assessing heavy metal sources in agricultural soils of an European Mediterranean area by multivariate analysis. Chemosphere, 65(5):863-872. doi.org/10.1016/j.chemosphere.2006.03.016

MITILENI C., GUMBO J., MUZERENGI C., DACOSTA F. (2011) The distribution of toxic metals in sediments: Case study of new union gold mine tailings, Limpopo, South Africa. Mine Water—Managing the Challenges; IMWA: Aachen, Germany.

MATOCHA C.J., ELZINGA E.J., SPARKS D.L. (2001) Reactivity of Pb (II) at the Mn (III, IV)(oxyhydr) oxide− water interface. Environ. Sci. & tech., 35(14):2967-2972. doi.org/10.1021/es0012164

MOHD S.E., MOHD S.H., SHAMSIAH A.R., NAZARATUL A.A.S., WEE B.S., EZWIZA S. (2014) Ecological risk assessment of heavy metal in surface sediment collected from Tuanku Abdul Rahman National Park, Sabah.

MOHIUDDIN K.M., ZAKIR H.M., OTOMO K., SHARMIN S., SHIKAZONO N. (2010) Geochemical distribution of trace metal pollutants in water and sediments of downstream of an urban river. International Journal of Environmental Science & Technology, 7(1):17-28. doi.org/10.1007/BF03326113

MULLER G. (1969) Index of geoaccumulation in sediments of the Rhine River. Geojournal, 2:108-118.

MUNYAI A.H., FOSSO-KANKEU E., WAANDERS F. (2016) Biological influence on the mobility of metals from mine tailing dump located in Krugersdorp area. Intern. J. of Sci. and Res. ISSN, pp.2319-7064.

NRIAGU J. O., BHATTACHARYA P., MUKHERJEE A. B., BUNDSCHUH J., ZEVENHOVEN R., LOEPPERT R. H. (2007) Arsenic in soil and groundwater: an overview. Trace Metals and other Contaminants in the Environment, 9:3-60.

NOVHE N.O., YIBAS B., NETSHITUNGULWANA R., LUSUNZI R. (2014) Geochemical and mineralogical characterization of mine residue deposits in the Komati/Crocodile catchment, South Africa: an assessment for acid/alkaline mine drainage. An interdisciplinary response to mine water challenges. China University of Mining and Technology Press, Xuzhou, ISBN, pp.978-7.

RAHMAN S.H., KHANAM D., ADYEL T.M., ISLAM M.S., AHSAN M.A., AKBOR M.A. (2012) Assessment of heavy metal contamination of agricultural soil around Dhaka export processing zone (DEPZ), Bangladesh: implication of seasonal variation and indices. Appl. Sci., 2(3):584-601. doi.org/10.3390/app2030584

REMY E. (2013) Planning of tailings dams rehabilitation for land use options at Chirano.

RHOADES, J. D. (1982) In Methods of Soil Analysis, Part 2. Second Edition (A.L. Page, R.H. Miller and D. R. Keeney, Eds.). American Society of Agronomy, Inc., Madison.

ROUSSEL, C., BRIL, H., FERNANDEZ, A. (2000) Arsenic speciation: involvement in evaluation of environmental impact caused by mine wastes. J. of Environ. Qua., 29(1):182-188. doi:10.2134/jeq2000.00472425002900010023x

SHERENE T. (2010) Mobility and transport of heavy metals in polluted soil environment. In Biological Forum—An Intern. J., 2(2):112-121

SALOMONS W., FÖRSTNER U. (2012) Environmental management of solid waste: Dredged material and mine tailings. Springer Sci. & Bus. Media.

SINGO N.K. (2013) An assessment of heavy metal pollution near an old copper mine dump in Musina, South Africa (MPhil. dissertation).

STOFFERS P., GLASBY G. P., WILSON, C. J., DAVIS K. R. , WALTER P. (1986) Heavy metal pollution in Wellington Harbour. New Zealand journal of marine and freshwater research, 20(3):495-512. doi.org/10.1080/00288330.1986.9516169

TAYLOR S.R., MCLENNAN S.M. (1995) The geochemical evolution of the continental crust. Rev. of Geophy., 33(2):241-265. doi.org/10.1029/95RG00262

TAYLOR S. R., MCLENNAN S. M. (1985) The Continental Crust: Its Composition and Evolution. Blackwell, Oxford.

THORNTON I. (1996) Impacts of mining on the environment; some local, regional and global issues. Appl. geochem., 11(1-2):355-361. doi.org/10.1016/0883-2927(95)00064-X

TIAN K., HUANG B., XING Z., HU W. (2017) Geochemical baseline establishment and ecological risk evaluation of heavy metals in greenhouse soils from Dongtai, China. Ecol. Indic., 72:510-520. doi.org/10.1016/j.ecolind.2016.08.037

TOMLINSON D.L., WILSON J.G., HARRIS C.R., JEFFREY D.W. (1980) Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. 33(1):566. doi.org/10.1007/BF02414780

TWYMAN R.M. (2005) Sample dissolution for elemental analysis: wet digestion V: Encyclopedia of analytical science. Vol. 8. Worsfold P., Townshend A., Poole C.

VICK S.G. (1990) Planning, design, and analysis of tailings dams. BiTech.

YONGMING H., PEIXUAN D., JUNJI C., POSMENTIER E.S. (2006) Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. Sci. of the total environ., 355(1-3), pp.176-186. doi.org/10.1016/j.scitotenv.2005.02.026

NIVEAUX DE MÉTAUX LOURDS ET ÉTAT DE CONTAMINATION D'UN BARRAGE DE RÉSIDUS MINIERS DÉCLASSÉ AU GHANA

Résumé

La pollution par les métaux lourds provenant des résidus miniers est devenue une préoccupation mondiale majeure en raison de sa toxicité, de sa persistance et de son potentiel accumulateur ayant des effets néfastes sur la santé publique et les récepteurs de l'environnement. Dans le but de déterminer l'état de contamination d'une installation de stockage de résidus (TSF 2) désaffectée provenant de la mine d'or Chirano (CGM), neuf échantillons de carottes de résidus miniers ont été recueillis à une profondeur de 20 cm sur une grille de 8100 m2. Concentrations d'As (0,7 à 3,3), de Pb (1,3 à 2,2), de Cr (0,9 à 1,9), de Cd (2,0 à 2,6), de Cu (5,5 à 6,5), de Zn (2,4 à 3,6) et de Fe (4,5 à 12) mg / kg étaient inférieurs aux limites permises FAO / OMS. La concentration de métaux lourds variait statistiquement entre les sites d'échantillonnage (p <0,05). L'indice de géoaccumulation et le facteur de contamination ont révélé que le TSF 2 n'est pas contaminé par l'As, le Pb, le Cr, le Cu, le Zn et le Fe. Cependant, les résidus miniers étaient considérablement enrichis en cadmium et donc susceptibles de présenter un risque écologique pour l'environnement. En général, la digue à stériles ne se détériore pas progressivement en fonction de l'indice de charge de pollution. Les résultats de cette étude contribueraient à la base de données environnementale des résidus miniers de la mine d'or à CGM afin de faciliter la restauration future de l'installation de stockage des résidus.

Mots-clés: Facteur de contamination, indice de géo-accumulation, facteur d'enrichissement, indice de charge de pollution, facteur de risque écologique.

LIVELLI DI METALLI PESANTI E STATO DI CONTAMINAZIONE DI UNA DIGA DI DECANTAZIONE DISMESSA IN GHANA

Riassunto

L'inquinamento da metalli pesanti degli sterili è diventato una delle principali preoccupazioni a livello mondiale a causa della sua tossicità, persistenza e potenziale accumulativo con effetti dannosi sulla salute pubblica e sui recettori ambientali. Nel tentativo di determinare lo stato di contaminazione di un impianto di stoccaggio degli sterili dismesso (TSF 2) dalla Chirano Gold Mine (CGM), nove campioni di base di residui di miniere sono stati raccolti fino a una profondità di 20 cm all'interno di una griglia di 8100 m2. Concentrazioni di As (da 0,7 a 3,3), Pb (da 1,3 a 2,2), Cr (da 0,9 a 1,9), Cd (da 2,0 a 2,6), Cu (da 5,5 a 6,5), Zn (da 2,4 a 3,6) e Fe (da 4,5 a 12) mg / kg erano inferiori ai limiti consentiti dalla FAO / OMS. La concentrazione di metalli pesanti variava statisticamente tra i siti di campionamento (p <0,05). L'indice di geoaccumulo e il fattore di contaminazione hanno rivelato che, il TSF 2 è incontaminato con As, Pb, Cr, Cu, Zn e Fe. Tuttavia, le operazioni di sminamento sono state significativamente arricchite con Cd, e quindi potrebbero rappresentare un rischio ecologico per l'ambiente circostante. In generale, la diga di sterilizzazione non si deteriora progressivamente in base all'indice del carico inquinante. I risultati di questo studio contribuirebbero alla banca dati ambientale del tailinging delle miniere d'oro presso la CGM per assistere il futuro risanamento della struttura di stoccaggio del tailing.

Parole chiave: *fattore di contaminazione, indice di geoaccumuloa, fattore di arricchimento, indice del carico di inquinamento, fattore di rischio ecologico.*